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Estimating the response of wildlife communities to coastal dune construction

Scott A. Martin[a,*], Rhett M. Rautsaw[b,1], M. Rebecca Bolt[c], Christopher L. Parkinson[d,2], Richard A. Seigel[a]

[a] Department of Biological Sciences, Towson University, 8000 York Road, Towson, MD 21252, USA
[b] Department of Biology, University of Central Florida 4000 Central Florida Blvd., Orlando, FL 32816, USA
[c] Integrated Mission Support Services, Mail Code IMSS-200, Kennedy Space Center, FL 32899, USA
[d] Department of Biology, University of Central Florida 4000 Central Florida Blvd, Orlando, FL 32816, USA

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ABSTRACT

Coastal ecosystems worldwide are being impacted by sea-level rise caused by climate change. As mitigation efforts increase to protect these threatened ecosystems, a deeper understanding of how wildlife adapt to coastal management techniques is needed. We monitored three constructed sand dunes (built in 2010 and 2014) and two natural dunes in central Florida from June 2015 through June 2016 to assess the impact of dune construction as a management technique on terrestrial vertebrates. Specifically, we tested if constructed dunes accumulated and maintained similar community composition and species richness to natural dunes. We used AHDriFT, a game camera-based trapping technique, to monitor terrestrial wildlife communities in both the natural and human-modified landscapes. After 4502 camera nights, we documented 2537 unique photo-capture events, comprised of 33 different species. Species communities were compared by constructing species accumulation curves for each dune type, and by modeling community similarity through multivariate hierarchical clustering. Species accumulation curves overlapped among all dune types, and the cluster analysis showed no pattern separating natural and constructed dunes. However, PERMANOVA found a difference between constructed and natural dunes, which was verified by a NMDS ordination that separated out constructed and natural dunes. Differences between dunes was likely driven by rare species, as commonly observed species overlapped across all dunes, including one protected species. Given the similarity between overall species richness, and that differences in community composition may be due to microhabitat variation and species rarity, we conclude that constructing dunes to increase coastal resilience does not negatively impact endemic wildlife in coastal zones and may provide suitable habitat for many wildlife species.

1. Introduction

Coastal ecosystems are ranked among the most threatened ecosystems worldwide due to a multitude of threats (Harris et al., 2015; Spalding et al., 2014). In addition to shifting temperatures, coastlines face rising sea levels and an increased severity in annual storms due to climate change (Scavia et al., 2002; Overpeck and Weiss, 2009; Zhang et al., 2013). Conversely, most research on climate change and its effects on wildlife species focuses on the impacts of increasing temperature and shifting weather patterns, while ignoring the immediate impacts of rising sea level (but see Schlacher et al., 2007 and Spalding et al., 2014; Noss, 2011; Reece et al., 2013). Mitigation for sea-level rise often emphasizes protecting human structures or impacts on marine wildlife, while neglecting terrestrial vertebrates (Noss, 2011). Due to these shortcomings, as sea levels increase, many plants and terrestrial animals are likely to be trapped without mitigation and management plans (Schlacher et al., 2007; Noss, 2011; Reece et al., 2013). Given that coastal ecosystems tend to have high endemic biodiversity, understanding how wildlife species respond to different management scenarios in coastal ecosystems will be critical as the impacts of climate change worsen (Schlacher et al., 2007; Harris et al., 2015; Jones et al., 2017).

* Corresponding author. Department of Evolution, Ecology and Organismal Biology, The Ohio State University, 318 W 12th Avenue, Columbus, OH 43210, USA.
E-mail address: martin.2537@osu.edu (S.A. Martin).
[1] Current affiliation: Department of Biological Sciences, Clemson University, 190 Collings Street, Clemson, SC 29634, USA.
[2] Current affiliation: Department of Biological Sciences and Department of Forestry and Environmental Conservation, Clemson University, 190 Collings Street, Clemson, SC 29634, USA.

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Coastal management efforts fall into two broad categories: 'hard' engineering or 'soft' engineering methods. 'Hard' engineering methods (e.g. sea walls) focus on using permanent structures to halt erosion, but often increase the overall loss of natural beach areas (Bernatchez and Fraser, 2011; Jones et al., 2017). 'Soft' engineering methods include sediment supplementation and dune construction, both of which aim to replace lost beach area to minimize overwash erosion during storms, increasing the resilience of sandy coastlines (Schlacher et al., 2007; Harris et al., 2015). For wildlife, dune construction is considered a minor disturbance and may be part of larger management plans to protect biodiversity in coastal areas, but more research on the response of terrestrial wildlife is sorely needed (Spalding et al., 2014; Harris et al., 2015; Martin et al., 2017a).

To assess the response of wildlife communities to dune construction, we compared vertebrate communities between three constructed and two natural dunes in coastal Florida. Florida is a major biological hotspot in the United States, and because no part of the state is greater than 150 km from a shoreline, climate-change induced sea-level rise is a growing threat to wildlife throughout the state (Reece et al., 2013; Noss et al., 2015). We aimed to estimate community composition on constructed and natural dunes, focusing on small mammals and reptiles, to determine whether constructed dunes accumulate and maintain species diversity equal to nearby natural dunes. We hypothesized that wildlife use constructed dunes as habitat similar to natural dunes; therefore, we expect to find community composition and species richness to have no differences between constructed dunes and natural dunes. Such results would indicate dune construction may function to protect coastal ecosystems and endemic wildlife as sea-level rise worsens.

2. Methods

2.1. Study site and monitoring design

We monitored two natural dunes and three constructed dunes at the John F. Kennedy Space Center/Merritt Island National Wildlife Refuge (MINWR) along the eastern shore of Florida from June 2015 through June 2016. Merritt Island is a barrier island that comprises one of the largest protected areas along the eastern U.S. coast, covering over 570 km^2, with many endemic species (Breininger et al., 1994). A combination of temperate Carolinian and tropical Caribbean species form the native flora and fauna assemblages, including several state and federally listed species, such as the southeastern beach mouse (*Peromyscus polionotus niveiventris*), eastern indigo snake (*Drymarchon couperi*), and gopher tortoise (*Gopherus polyphemus*) (Breininger et al., 1994).

Sea-level rise is a serious threat to MINWR, with recent storms eroding areas 25–60 m wide along the coastline (Rosenzweig et al., 2014; Foster et al., 2017). In 2010, NASA proposed the construction of new dunes to reduce further overwash erosion and to protect critical structures in the wake of Hurricane Sandy (Rosenzweig et al., 2014). A 214 m long dune was completed in 2010, with a larger dune extending 445 m long to the north and 1,088 m long to the south of the 2010 dune being completed in 2014. Post-construction, all constructed dunes were hand-planted with native herbaceous flora to promote stability (sea oats [*Uniola paniculata*] was the dominate species on the newly made dunes). In total, the constructed dunes were 1.77 km long, an average of 24.4 m wide, with a peak height of 18.3 m and covered over 4.3ha. In comparison, nearby natural dunes varied in both height and width, with the asymmetric northern dune having an average height of 16 m and width varying from 5 to 50 m. The southern natural dune height ranged from 1 to 9 m and was roughly symmetrical with a width of 30 m. Both natural dunes were dominated by a mixture of sea grapes (*Coccoloba uvifera*) and sea oats, with localized patches of the invasive Brazilian pepper-tree (*Schinus terebinthifolius*). The surrounding landcover of all dunes was a mixture of coastal strand and scrub, salt marsh, infrastructure and associated ruderal areas, and open beach/ocean.

To assess coastal wildlife communities, we used a series of game cameras deployed with the Adapted-Hunt Drift Fence Technique (AHDriFT) arranged throughout the constructed and natural dunes (Martin et al., 2017b). We deployed 18 NatureView® (Bushnell Corp., Overland Park, KS, USA) cameras in pairs at opposite ends of nine 7 m × 0.6 m x 0.63 m drift fences constructed of wooden, oriented strand boards supported by 1 m gardening stakes from June 2015 through June 2016 (Martin et al., 2017b). However, two cameras malfunctioned shortly after placement in the field and were removed from later analysis. Each camera was contained in a secondary housing structure following recommendations given by Martin et al. (2017b) and set to standardized motion-sensitive setting of three burst photos per trigger. Each drift fence (pair of cameras) was considered an independent camera station. Two camera stations were placed on four of the five dunes, while the northern 445 m 2014 constructed dune contained a single camera station. Camera stations were separated by 0.1–1.5 km.

2.2. Data management and analysis

Each camera station was treated as an independent survey unit. We removed duplicate captures by retaining captures separated by a minimum of 60 min using the package 'camtrapR' in R (version 3.3.4; Niedballa et al., 2016; Martin et al., 2017b). Due to unequal sampling (number of trap nights), we used sampled-based rarefaction, and extrapolated our curves out to 2000 trap nights (Colwell et al., 2012). Rarefaction and calculation of 95% confidence intervals for the species richness curves were done using the 'iNext' package in R (version 2.0.12; Hsieh et al., 2016). To assess similarities in species diversity between dune types, we ran a hierarchical cluster analysis using the package 'vegan' in R (version 2.4–6; Oksanen et al., 2008). First, dissimilarity is calculated between pairs of sites to generate a distance matrix. Then, hierarchical clustering iteratively pairs groups of sites by minimizing dissimilarity between them. Finally, groups the resulting pairs of sister sites are grouped based on the same criterion. We then estimated the goodness of fit between the mapped clusters and our original data by calculating the correlation between the cophenetic distances for the clusters (i.e. intergroup dissimilarity) and the distance (dissimilarity) matrix of our original data.

We used a permutational multivariate analysis of variance (PERMANOVA) implemented in vegan through the 'adonis' function to test for differences between constructed and natural dune communities using distance matrices based on the untransformed count data, and did not remove any species from the dataset (version 2.4–6; Anderson, 2001; Cao et al., 2001; Oksanen et al., 2008; O'Hara and Kotze, 2010; Poos and Jackson, 2012). Ordinations were then plotted using nonmetric multidimensional scaling (NMDS) in two dimensions with vegan's 'metaMDS' function using the Bray-Curtis distance and the default settings (Kruskal, 1964; Oksanen et al., 2008). Stress values for the NMDS plot were assessed to ensure good fit in a two-dimensional space, with a value less than 0.2 considered acceptable.

3. Results

During one year of surveying, 16 cameras photographed wildlife without errors over 4502 trap-nights (N = 927 for 2010 constructed dune, N = 1681 for 2014 constructed dunes, and N = 1894 for natural dunes) resulting in 2537 distinct capture events (N = 407 for 2010 constructed dune, N = 695 for 2014 constructed dunes, and N = 1435 for natural dunes). Each camera station documented an average of 17 species (± 2 SE, N = 16; Supplementary Table 1). Two cameras were removed from the final dataset due to malfunctions in recording date; one from the 2010 constructed dune, and one from the southern natural dune. Based on our analyses, there was no difference between the average number of species observed along each dune (Table 1). Additionally, confidence intervals for the species accumulation curves

Table 1
Mean and standard error of the number of unique species observed at each camera fence in each dune category at the Merritt Island National Wildlife Refuge, FL, USA.

Dune (# camera fences)	Mean # Species Per Fence	Standard Error (SE)
2010 Constructed (2)	18.5	2.12
2014 Constructed (3)	16.6	2.51
Natural Dune (4)	16.5	1.73

overlapped across all dune categories (Fig. 1).

Our hierarchical clustering analysis placed all constructed dunes between the two pairs of natural dunes, indicating that the pairs of natural dunes had more dissimilar communities from each other than from the constructed dune communities, which all had more similar communities than the natural dunes (Fig. 2). The correlation between the cophenetic distances of the cluster dendrogram and the original site-dissimilarity matrix was 0.85, indicating robust fit. In contrast to the clustering analysis, PERMANOVA analysis detected a difference between constructed and natural dune communities ($F_{1,16} = 4.48$, $P = 0.018$, $R^2 = 0.39$). Similarly, our ordination, which fit the data with two axes (stress = 0.10), demonstrated separation between the natural dunes and the constructed dunes (Fig. 3). The contrasting results obtained from our hierarchical clustering and ordination are largely driven by the influence of rare species that were captured on cameras infrequently, while the most common species were the same across all camera stations, with southeastern beach mice, spotted skunks (*Spilogale putorius*), hispid cotton rats (*Sigmodon hispidus*), black racers (*Coluber constrictor*), and six-lined race runners (*Aspidoscelis sexlineata*) representing most of the captures (Fig. 3, Supplemental Table 1).

4. Discussion

Based on our results, we conclude that the dunes differ significantly in community composition, but these differences were largely due to rarely documented species which may have been detected more often if the survey was continued for a longer time (Cao et al., 2001). Overall, species richness remained similar across our dunes, indicating that dunes are regularly used and are a viable management option (Fig. 1). Additionally, because the constructed dunes are recently disturbed and in an early stage of ecological succession, habitat preferences may play a large role in the community composition. For example, two of the three detected invasive species (both *Hemidactylus* ssp.) were associated with constructed dunes (Fig. 3). These species may have colonized the constructed dunes via 'hitchhiking' on vehicles or plants used to build the dunes, as *Hemidactylus* had not been widely observed along the beach, and invasive species have a much easier time colonizing recently disturbed areas (Hobbs and Huenneke, 1992; Marvier et al., 2004; Chapple et al., 2016). Skinks (both *Plestiodon* ssp. and *Scincella lateralis*), which prefer habitats with an abundance of loose sandy soils, were only documented on constructed dunes, while species preferring damper habitats (ex. most amphibians and striped mud turtles; *Kinosternon baurii*) were associated with the lower and more compacted natural dunes (Fig. 3; Mount, 1963). These results indicated that differences in community composition may be from the availability of microhabitats on each dune; the constructed dunes had higher proportions of open sandy areas, and low vegetation coverage that may attract lizards, while the natural dunes often had dense, shrubby vegetation to protect amphibians from desiccation (Kacoliris et al., 2009; Hall Cushman et al., 2010; Martin et al., 2017a). Differences may also be due to the short period of time since the start of construction (maximum of 6 years); prior studies have estimated that it may take up to 68 years for communities to completely converge, depending on the generation time of the organisms involved (Wassenaar et al., 2005).

Of the 25 protected species that use coastal habitat at KSC, we documented two protected species on the constructed dunes (the southeastern beach mouse and gopher tortoise) and a third (the eastern indigo snake) on the natural dunes (Fig. 4, Supplementary Table 1; Breininger et al., 1994). Only gopher tortoise hatchlings were documented on cameras, but this is due to the adults' large size preventing them from entering the camera buckets; adults were observed frequently on the constructed dunes (Fig. 4; Martin et al., 2017a). While the indigo snake was only seen once in the natural dunes, an additional individual was observed on the 2010 dune during a vegetation survey (M.R. Bolt, pers. observation). The southeastern beach mouse was documented at every camera station, and this species appears to heavily utilize the constructed dunes (Fig. 4). Based on our trapping data and incidental observations, all protected species made use of the constructed dunes and two of them showed no difference in usage between constructed versus natural areas (Fig. 3).

Despite the difference between dune categories, constructed dunes acted as habitat for native wildlife supporting both similar numbers of species and the same common species when compared to natural dunes nearby (Fig. 2). Previous studies have documented a time lag before observing a positive impact of dune rehabilitation on wildlife communities, which may explain some of the divergence in our observations (Ferreira and Van Aarde, 1996; van Aarde et al., 1996; Wassenaar et al.,

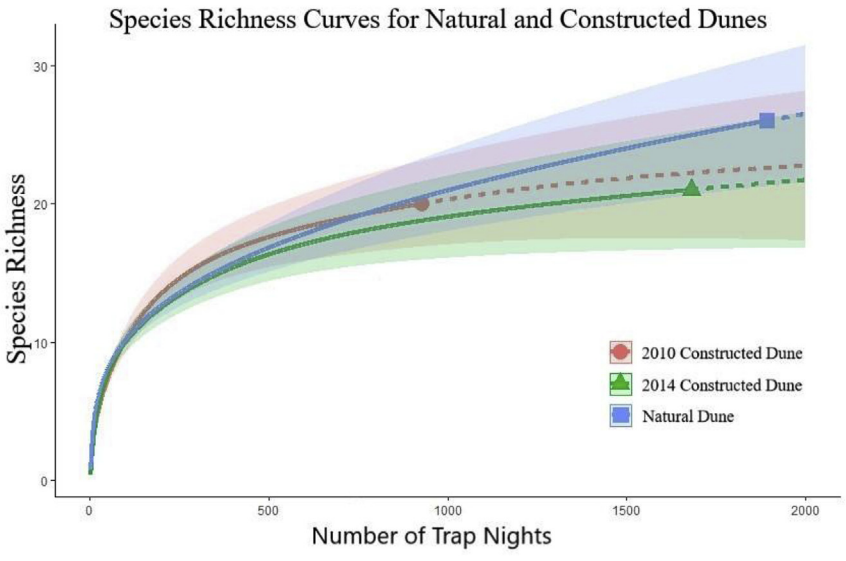

Fig. 1. Species accumulation curves and 95% confidence intervals along the three dune categories at Merritt Island National Wildlife Refuge, Florida, USA. 'Trap night' was calculated by the number of calendar days since the first camera station was placed along a dune multiplied by the total number of cameras on each dune category. Solid lines are estimates of richness via interpolation, while dashed lines are extrapolations of richness to account for unequal sample sizes.

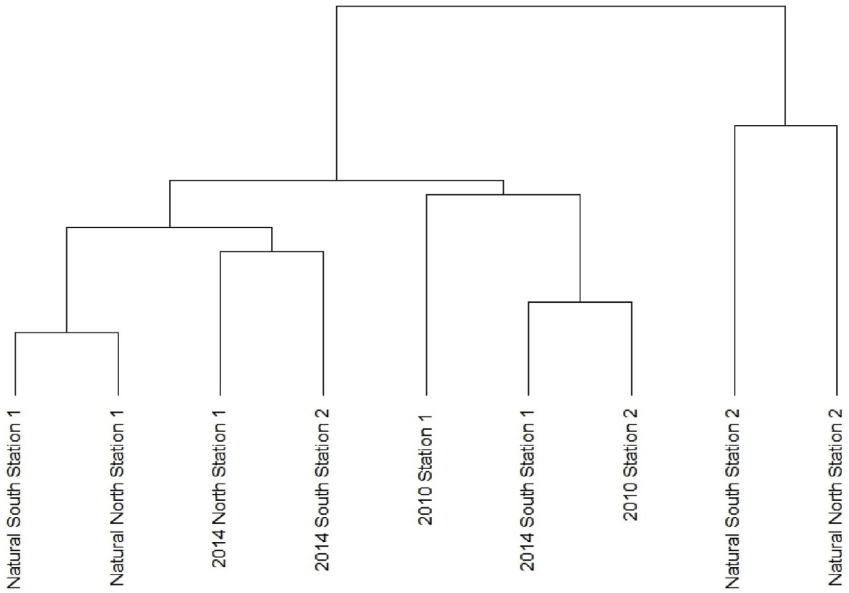

Fig. 2. Dendogram of the hierarchical cluster analysis of wildlife communities across 9 survey stations located in two natural dunes, a dune constructed in 2010, and two dunes constructed in 2014 at the Merritt Island National Wlidlife Refuge, Florida, USA.

2005). Furthermore, retention of all recorded species likely affected the results of both the PERMANOVA and ordination analyses. Rare species were kept during the analysis because removing species may have hidden true effects and biased our results (Poos and Jackson, 2012). While our results were only comprised of one year of data, our results do cover a broader temporal span, as the dunes were two and five-years-old at the start of our surveys. Caution should be taken since this study focused on a single shoreline, but the fact that several species of concern were photographed shows that constructed dunes benefited native species. However, given the limited spatial scope of this study, we recommend more studies be done comparing the wildlife communities of natural and artificially constructed dunes.

5. Conclusions

As increasing sea level threatens larger stretches of coastline worldwide, the need for management to mitigate this impact will also rise. A critical aspect of mitigation is improving coastal resilience to minimize the impact of worsening sea-level rise and storm surges. Our study reinforces that dune construction acts as a potential management option that increases coastal resilience while also providing habitat for native wildlife. In areas where coastal erosion threatens wildlife, dune construction may be a viable option for mitigation, as has been noted in prior studies (Ferreira and Van Aarde, 1996; van Aarde et al., 1996; Wassenaar et al., 2005). However, for mitigation to work, it is important that native species have source populations to supply the new habitat, and to be aware of potential time lags for communities to match natural dunes (Richardson et al., 2000; Wassenaar et al., 2005; Martin et al., 2017a).

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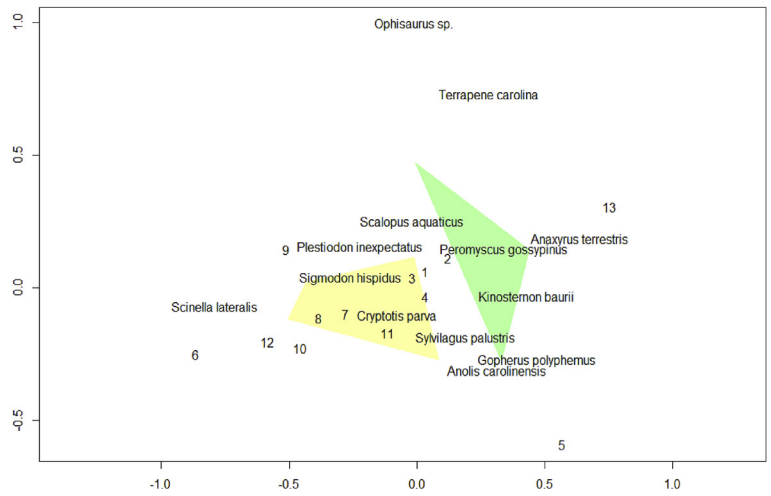

NUMBER	SPECIES
1	*Coluber constrictor*
2	*Aspidoscelis sexlineata, Anolis sagrei, Peromyscus polionotus*
3	*Spilogale putorius, Pantherophis sp.*
4	*Masticophis flagellum*
5	*Pseudacris ocularis, Opheodrys aestivus*
6	*Crotalus adamanteus, Hemidactylus turcicus*
7	*Troglodytes aedon*
8	*Thamnophis sirtalis*
9	*Plestidon egregious*
10	*Gastrophryne carolinensis*
11	*Hemidactylus garnotii*
12	*Sistrurus miliarius*
13	*Nerodia clarkii, Drymarchon couperi*

Fig. 3. NMDS plot based on Bray-Curtis distance of dune communities at 9 sites in coastal Florida, USA. Species and site scores using two axes are shown. Sites are represented as polygons, with the natural dunes on the right, and constructed dunes on the left. To reduce overlap, several species are listed as numbers, and identified in the legend to the left.

Fig. 4. Example images of wildlife documented on both constructed and natural dunes. From top left, clockwise: Southern Toad (*Anaxyrus terrestris*), Southeastern Beach Mouse (*Peromyscus polionotus niveiventris*), Eastern Diamondback Rattlesnake (*Crotalus adamanteus*), Eastern Spotted Skunk (*Spilogale putorius*), Gopher Tortoise (*Gopherus polyphemus*), Florida Box Turtle (*Terrapene carolina*), Striped Mud Turtle (*Kinosternon baurii*), Mole Skink (*Plestiodon egregius*), Eastern Indigo Snake (*Drymarchon couperi*). All images are from the Merritt Island National Wildlife Refuge, Florida, USA.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.ocecoaman.2018.04.021.

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